Thermal Insulation System Analysis Tool (TISTool) User's Manual Version 1.0.0

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List of Symbols and Acronyms

A – area perpendicular to heat transfer at a given layer, m^2
CVP – Cold Vacuum Pressure, millitorr
DAM – Double Aluminized Mylar
k – apparent thermal conductivity, mW/m-K
L – length of a cylinder, m
ln – natural logarithm (base e) of a function or variable
Q – rate of heat transfer, W
R_n – thermal resistance of a given division, K/W
r_n – radius at given division n, m
T_n – temperature at given division n, K
X_n – thickness at given division n, m

Greek
λ – thermal conductivity, W/m-K
π – irrational number determined by the ratio of the circumference to the diameter of a circle

Subscript
i – division of material at which current calculation is taking place
oafi – over-all field installed

1.0 Introduction

The Thermal Insulation System Analysis Tool (TISTool) was developed starting in 2004 by Jonathan Demko and James Fesmire The first edition was written in Excel and Visual Basic as macros It included the basic shapes such as a flat plate, cylinder, dished head, and sphere The data was from several KSC tests that were already in the public literature realm as well as data from NIST and other highly respectable sources This was presented at CEC 2007 in Chattanooga, TN and was published in Advances in Cryogenic Engineering, Vol 53A (1) More recently, the tool has been updated with more test data from the Cryogenics Test Laboratory and the tank shape was added Additionally, the tool was converted to FORTRAN 95 to allow for easier distribution of the material and tool

2.0 Theoretical Discussion

The calculations are based on one-dimensional heat conduction of standard basic shapes The current shapes include a plane, cylinder, sphere, dished head, and tank (combination of cylinder and dished head) The basic equation for a plane wall is

$$Q = -\lambda A \frac{T_i - T_{i-1}}{X_i - X_{i-1}} \quad (1),$$

for a cylinder,

$$Q = -2\pi\lambda L \frac{T_i - T_{i-1}}{\ln\left(r_i / r_{i-1}\right)} \quad (2),$$

and for a sphere,

$$Q = -4\pi\lambda r_i r_{i-1} \frac{T_i - T_{i-1}}{r_i - r_{i-1}} \quad (3)$$

In equations (1-3), λ is the thermal conductivity and is assumed constant over the finite thickness between X_i and X_{i-1} or r_i and r_{i-1} The thermal conductivity is assumed to vary as the temperature and material of the divisions change and is determined from test data that is documented in Appendix B All other variables are defined in the List of Symbols The general finite differencing setup for the flat plate and cylinder are shown in Figure 1 The energy is balanced at all locations by assuming an initial temperature distribution and determining the thermal resistance (eq 4) at each division and iteratively solving until the Q's converge to a given tolerance

$$R_i = \frac{T_i - T_{i-1}}{Q_i} \quad (4)$$

Typically the maximum change in temperatures between iterations can be reduced to less that 10^{-9} K in less than 25 iterations A block diagram of the logic is shown in Figure 2

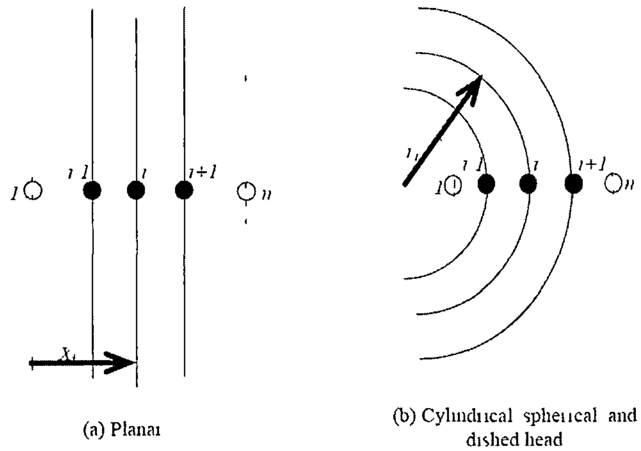

Figure 1 Illustration of divisions of an insulation system for (a) planar and (b) cylindrical, spherical, and dished head geometries (used from Ref 1)

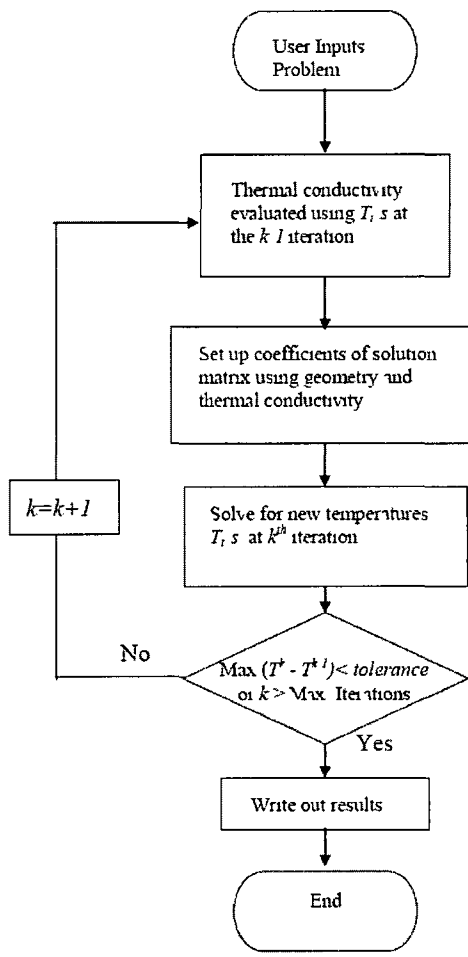

Figure 2 Flow chart of the iteration process for variable thermal conductivity calculation

3.0 User Interface and Inputs

The user can interface with the TISTool in two different ways The first uses only inputs when queried from the TISTool command window while the second uses a user developed input file

and minimal inputs to the TISTool command window At any point throughout the setup, if a wrong keystroke is entered, the program will often merely send the user back one step to reenter that parameter, however it may send the user back to the beginning of the process if a large error is made

Upon initiating TISTool exe, the screen should look similar to Figure 3 Pressing enter will show the instructions on operating within the TISTool command window

```
Welcome to the Thermal Insulation Systems Analysis Tool
Written by:
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     Cryogenics Test Laboratory
     MS: NE-F6
     Kennedy Space Center, FL 32899
     (321) 867-4865

          and

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     Applied Superconductivity Group
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     Oak Ridge, TN 37831
     (865) 574-1469

                    This program is from March 2010
If you think the insulation database has been updated since that time,
                   please contact one of the authors.


press Enter to continue.
```

Figure 3 TISTool Introductory Screen

After the Instructions come the insulation data update options that are discussed in section 5 2 The next important screen encountered is the geometry selection shown in Figure 4 The different geometries available with the TISTool are listed here and include a flat plate, cylinder, sphere, dishhead, and tank Choosing any of option 1-5 causes you to continue in the TISTool command window (3 1), option 6 allows the use of an existing input file and operates under the instruction located in section 3 2

```
To begin calculation, please choose a geometry.
     1. Plane
     2. Cylinder
     3. Sphere/Fraction of a Sphere
     4. Dishhead (2:1)
     5. Tank
     6. Use existing input file: Tistool input.txt
     Enter a number between 1 and 6
```

Figure 4 Geometry selection

3 1 TISTool Command Window Inputs

At this point, the user has selected one of geometry options 1-5 and is ready to proceed to the system inputs Each geometry asks for different measurements to define the geometry selected, all lengths are in meters The "Plane" selection asks for planar area (m^2) The "Cylinder" selection asks for inner diameter (must be greater than 0) in meters and length of the cylindrical section in meters The "Sphere/Fraction of a Sphere" asks for inner radius (must be greater than 0) in meters and sphere fraction (between 0 and 1, this allows partially spherical domes) The "Dishhead (2 1)" selection asks for inner radius (must be greater than 0) in meters and dishhead

fraction (between 0 and 1) The "Tank" selection requires cylindrical radius (must be greater than 0), cylindrical length, and dishhead fraction (between 0 and 1, defines the shape of the domes) Figure 5 shows the process for a cylinder and other geometries are shown in the tutorial section

```
 Please insert the inner radius (m)
0.0254
 Please insert the cylinder length (m)
1.0
```

Figure 5 Defining the parameters of a cylinder

Next the boundary conditions are set Cold and warm boundary temperatures (input in Kelvin) are required with optional inputs for boundary convection (input in W/m^2-K) Figure 6 shows example inputs with a convection coefficient inputted on the warm boundary

```
 Please enter the cold boundary temperature in Kelvin
77.0
 Is there convection on the cold boundary? (Y/N)
n
 Please enter the warm boundary temperature in Kelvin
300
 Is there convection on the warm boundary? (Y/N)
y
     Please input the convection coeficient, h (W/m2-K)
22.7
```

Figure 6 Boundary Condition Entries with Warm Boundary Convection

The default temperature tolerance is set to 10-5 K and the default iteration limit is set to 1000 Either can be changes by typing a "n" as the appropriate input Generally both are well within the requirements for run time and accuracy for a given model Figure 7 shows the general statements involed in changing these parameters, additionally, they are changed in the planar tutorial (6 1)

```
 Is the default tolerance of 1.0*10^(-5) appropriate? (Y/N)
n
 Please enter your desired temperature tolerance (K)
0.0001
 Is the default maximum iterations of 1000 appropriate? (Y/N)
n
 Please enter your desired maximum number of iterations
50
```

Figure 7 How to change the default tolerances and maximum iterations

After defining the geometry of the model, the user then must select the proper materials Choosing one and pressing enter allows the user to cycle through the existing materials, once the end it reach, TISTool will loop back to the beginning Entering any number other than a material that is available will yield a warning message Figure 8 shows the first page of insulations that appear after initializing TISTool Materials with user numbers below 11000 are vacuum pressure dependant and require the additional input of vacuum pressure when defining the thermal properties of the material (see 6 1) Note the user is limited to 15 materials and 101 divisions

```
Please choose your next material

99999   User Defined Insulation

10102   'Glass Bubbles, K1, 3M'
10103   'Perlite Powder, Ryolex'
10104   'SOFI, BX-265, shaved'
10105   'SOFI, NCFI 24-124, shaved'
10106   'SOFI, NCFI 27-68, shaved'
10107   'SOFI, NCFI 24-124, with rind'
10108   'Nanogel Beads, Cabot, white'
10109   'Composite Beads, black'
10110   'LCI#1, MLI + Aerogel Blankets'
10111   'Layered Pyrogel, Aspen'

Please choose a material by entering the material number, enter 0 to finish or

1 to see more materials
```

Figure 8 Initial insulation systems that are available for use in TISTool

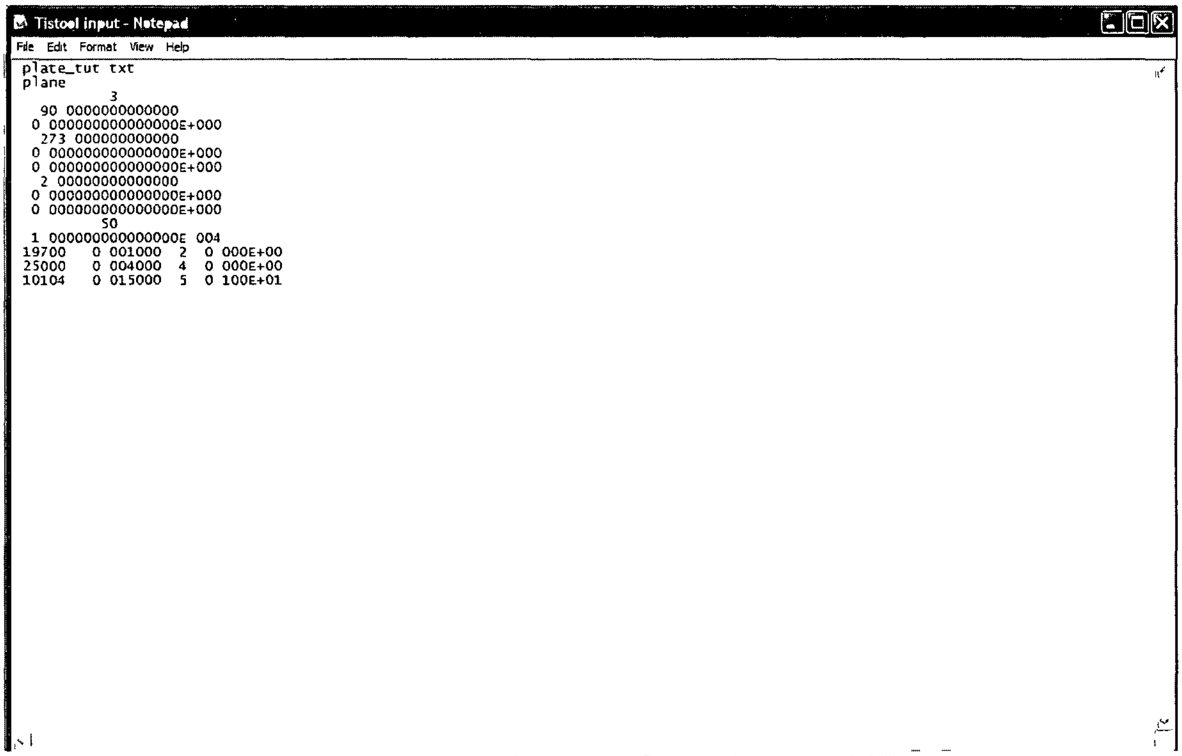
Once all of the materials have been selected, typing "0" exits the material selection menu All that remains is to name the output file (limited to 20 characters including the file extension) At this point the program does the thermal analysis and outputs the file with the results

3 2 User Input file

If the user desires to simply create their own input file, one can be created using the 6th option in the geometry definition menu The file should be named "Tistool input txt" and stored in the same file as the executable Figure 9 shows the input file for the plane tutorial Table shows the inputs with their type definition and units in TISTool as well as specific options if appropriate

The first line is the name of the output file (limited to 20 characters including spaces and file extension), this will be read into TISTool as a character string The second line defines the geometry (and the geometric dimensions that come later) Options on the second line are limited to "plane", "cylinder", "sphere", "dishhead", or "tank" Any other entry will result in no output and an error The third line specifies the number of materials (max 15) as an integer The fourth line specified the cold boundary temperature in Kelvin as a double precision number (up to 16 significant figures) The fifth line specifies the cold boundary convection coefficient in Watts per meter squared Kelvin as a double precision number (up to 16 significant figures), if no cold boundary convection is desired, insert "0 00" The sixth and seventh line are the warm boundary temperature and convection coefficient with the same rules as the inner boundary conditions The eighth line is the inner radius and is used for the cylinder, sphere, tank, and dishhead options as a double precision number (up to 16 significant figures) The ninth line is the planar area as a double precision number (up to 16 significant figures) for the plane geometry The tenth line is the cylinder length as a double precision number (up to 16 significant figures) used for the cylinder and tank options The eleventh line is the spherical fraction as a double precision number (up to 16 significant figures) used for the sphere, dishhead, and tank geometries The twelfth line is the number of iterations allowed before forcing an output as an integer The thirteenth line specifies the tolerance on the temperature convergence as a double precision number (up to 16 significant figures) The remaining lines (the number left should match the 3rd line) specify the materials to be used, first is the material code (5 digit integer), second is the thickness (10 characters – including decimal point - with 6 coming after the decimal point), third is the number of division (2 digit integer), and finally is the vacuum pressure (10 characters –

including decimal point - with 3 coming after the decimal point, the 10 characters include the E and the exponent, this number is read in as an exponent)



```
Tistool input - Notepad
File  Edit  Format  View  Help
plate_tut txt
plane
           3
  90 0000000000000
 0 000000000000000E+000
  273 000000000000
 0 000000000000000E+000
 0 000000000000000E+000
  2 0000000000000
 0 000000000000000E+000
 0 000000000000000E+000
          50
 1 000000000000000E 004
19700    0 001000  2   0 000E+00
25000    0 004000  4   0 000E+00
10104    0 015000  5   0 100E+01
```

Figure 9 Example user input file (see planar tutorial 6 1)

Table 1 User Input definitions

Row	Name	Type definition	Units	Comments
1	Output file name	Character *20		The 20 character limit includes the file extension
2	Geometry	Character		Choose one of Plane Cylinder Sphere Dishhead Tank
3	Number of materials	Integer		Cannot exceed 15
4	Cold Boundary Temperature	Double Precision	K	
5	Cold Boundary Convection	Double Precision	W/m^2-K	
6	Warm Boundary Temperature	Double Precision	K	
7	Warm Boundary Convection	Double Precision	W/m^2-K	
8	Inner Radius	Double Precision	m	Used for

				Cylinder Sphere Dishhead Tank
9	Planar Area	Double Precision	m^2	Used for Plane
10	Cylinder Length	Double Precision	m	Used for Cylinder Tank
11	Sphere Fraction	Double Precision		Between 0 and 1, Used for Sphere Dishhead Tank
12	# Iterations	Integer		Recommended is 1000
13	Tolerance	Double Precision	K	Recommended is 1 000E-5

The remaining number of lines should match the number in line 3 and each specifies a material Each material should have the following four items separated by a single space

	Material Code	Integer (5 digit)		Specifies the insulation
	Material Thickness	Number 10 characters with 6 coming after the decimal point	m	The 10 characters includes the decimal point
	# of Divisions	Integer (2 digit)		Total less than 101
	Vacuum Pressure	Engineering number (example 1 000E-003)	millitorr	10 characters total

4.0 TISTool Output File

The output file is named by the user and put into the same folder as the executable The output file includes information about the geometry (shape and size), both boundary conditions (warm and cold boundary conditions, tolerances and the number of allowed iterations), a summary of results (surface area, total heat load, heat fluxes – inner and outer, material system thickness, and over-all field installed thermal conductivity – k_{oafi}) The most important part is the bottom section that details each division The material, material code, thickness, apparent thermal conductivity, thermal resistance (as a function of distance through the system), temperature, and heat transfer through the division are listed Figure 11 shows an example output file Typically all of the Q(W) column should be identical unless either the file didn't converge, or the tolerance was set too high The k-value is the actual thermal conductivity used in the final iteration and thus is usually a function of temperature (if available) The thickness and thermal resistance ((r-

Ri)/(Ro-Ri)) columns are continuous in that they show the value from starting at the cold boundary to that of the current division

```
plate_tut - Notepad
File  Edit  Format  View  Help
This calculation used the basic geometry of a plane
   area      2 000 m^2
Boundary Conditions
   Inner Temperature        90 000 K
   Inner Convection          0 000 W/m^2-K
   Outer Temperature       273 000 K
   Outer Convection          0 000 W/m^2-K
   Tolerance               100E-03
   Maximum Iterations        50
Summary of Results
   Inner Surface Area          2 000 m^2
   Outer Surface Area          2 000 m^2
   Total Heat Load           190 251 W
   Inner Heat Flux            95 126 W/m^2
   Outer Heat Flux            95 438 W/m^2
   Thickness                  20 000 mm
   koafi                      10 430 mW/m K
Material                     Matl #  thickness (m)  k-value (mW/m-K)  (r-Ri)/(Ro-Ri)    T(K)      Q(W)
AL6061-T6 NIST                19700     0 0000       92047 7978         0 0000        90 000   190 251
AL6061-T6 NIST                19700     0 0005       92047 7978         0 0250        90 001   188 385
AL6061-T6 NIST                19700     0 0010       92048 0958         0 0500        90 001   190 885
G 10 Normal NIST              25000     0 0020         297 2101         0 1000        90 322   190 880
G-10 Normal NIST              25000     0 0030         297 6272         0 1500        90 643   190 874
G-10 Normal NIST              25000     0 0040         298 0438         0 2000        90 963   190 875
G 10 Normal NIST              25000     0 0050         298 4598         0 2500        91 283   190 876
SOFI  BX-265  shaved          10104     0 0080           7 8780         0 4000       127 626   190 876
SOFI  BX-265  shaved          10104     0 0110           7 8780         0 5500       163 970   190 876
SOFI  BX-265  shaved          10104     0 0140           7 8780         0 7000       200 313   190 876
SOFI  BX 265  shaved          10104     0 0170           7 8780         0 8500       236 657   190 876
SOFI  BX 265  shaved          10104     0 0200           7 8780         1 0000       273 000   190 876
```

Figure 10 Example TISTool Output File

5.0 TISTool Options

The TISTool has several options that allow for a broader and easier use of the tool These options include the ability for the user to create new insulation data files and to incorporate them seamlessly into the structure of the code (without changing the source code or recompiling) Also, at some point the Cryogenics Test Laboratory or other laboratories and agencies may decide to publish additional data for use, the standard is described below in how to create these files and how to update the appropriate files that allow TISTool to know that the new materials files exist and are able to be used Furthermore, multilayer insulations (MLI) receive a special treatment in the TISTool that is fully discussed here The MLI inputs are not editable, but still a further discussion of them will allow the user to understand the difference between these special materials and standard isotropic materials

5 1 Adding Insulation Systems

To import additional data sets, add the data set as a TIS file and the next time you run TISTool, merely update the insulation system file These files will be made available for download as they are generated by the Cryogenics Test Laboratory and other NASA facilities

5 1 1 Creating a TIS files

The TIS file has several major components the insulation number, the insulation name, the number of data points, and the actual data The correct entry of each of these is imperative to

ensure that the new insulation system will work with the TISTool Figure 11 shows the basic layout of the TIS file

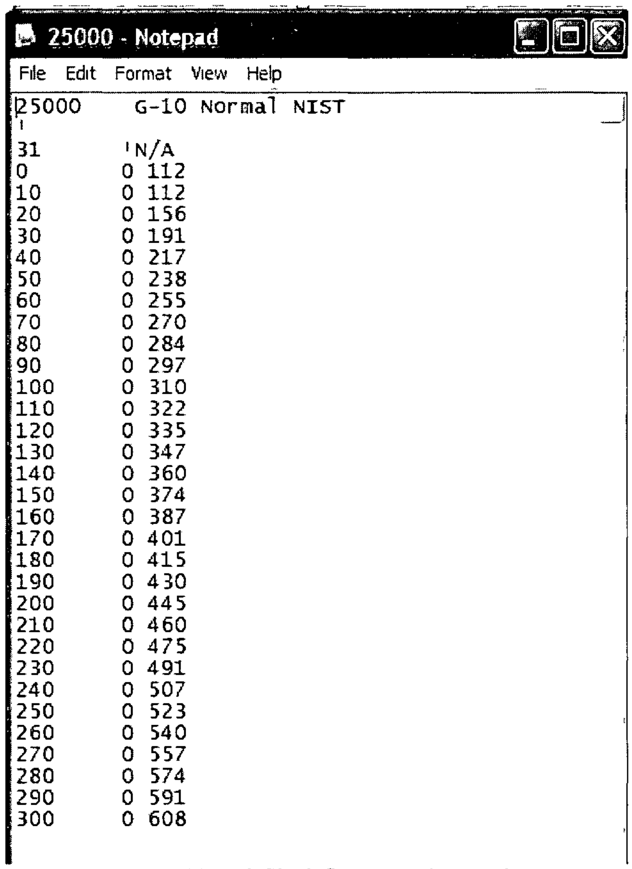
The first line contains both the material number (as referenced in the TISTool) and the material name Both are displayed as a part of the TISTool output, while the number is solely used during TISTool operation to specify the exact material Depending on the material type, there are several numbering conventions, these conventions determine the data to be input in the body of the file The first rule is that there cannot be any duplicate numbers, this will confuse the filing system, and overwrite previously existing data files Any material that is a function of vacuum pressure (fixed boundary temperature) should be numbered between 10100 and 10200 As of 4/19/2010, 17 of these 101 slots have been filled If at some point the need for data exceeds these slots, then that capacity will be expanded The numbers 27000 through 28000 have been set aside for hardcoded MLI functions, currently there are 11 hardcoded MLI functions The final number that has been reserved, is 99999, this is reserved for user inputed materials within the code itself The name of the material is limited to 50 characters including spaces and must be surrounded by quotation marks The name should at minimum give a common or trade name and also should indicate what vacuum level the data was taken at (ie high vacuum (HV, 10-3 torr), soft vacuum (SV, 1 torr), no vacuum (NV, 760 torr)) The material number and name should be seperated by a tab

The second line should have an exclamation point as it is commented out

The third line contains the number of data points (an integer) Following that should be a tab and an exclamation point and then and more information on the material that may be of interest to other users

The remainder of the file is filled with the data points For any materials that are a function of temperature, the format should be temperature then thermal condcutivity, seperated by a tab For any materials that are a function of vacuum pressure (i e material #s 10100 through 10200), the data should be in the format cold vacuum pressure and then thermal conductivity seperated by a tab The data is limited to one temperature or vacuum pressure data point per line

Examples of the input are shown in Figure 11 and Table 2



```
25000 - Notepad
File  Edit  Format  View  Help
25000     G-10 Normal NIST

31        N/A
0         0 112
10        0 112
20        0 156
30        0 191
40        0 217
50        0 238
60        0 255
70        0 270
80        0 284
90        0 297
100       0 310
110       0 322
120       0 335
130       0 347
140       0 360
150       0 374
160       0 387
170       0 401
180       0 415
190       0 430
200       0 445
210       0 460
220       0 475
230       0 491
240       0 507
250       0 523
260       0 540
270       0 557
280       0 574
290       0 591
300       0 608
```

Figure 11 TIS file definition and example

Table 2 General Rules and Guidelines for Insulation Material Data Files

Function	Rules/Requirements	Example	Limitations
Material Number	5 digits 10100 – 10200 reserved for materials as a function of vacuum level	11515	27000 – 28000, 99999 already taken
Material Name	max 50 characters, quotation marks on both side	'Pyrogel Blanket, 2 mm (KSC), NV'	50 characters including quotation marks and spaces
Number of Data Points	Must be an integer	7	
Temperature Data Points	Temp and k-value separated by a tab	179 0.0136	units Temperature K k-value W/m-K
Cold Vacuum Data Points	CVP and k-value separated by a tab	0.1 0.00132	units CVP millitorr k-value W/m-K

5 2 Updating the Insulation Systems in TISTool

The architecture of the TISTool allows for the easy addition and use of new material data The first option after the introduction and instructions is "If you would like to update your insulation file, please enter a 1 Otherwise, enter 0" When a 1 is input, a MS-Batch file searches the current file that the executable is stored in for any TIS (material data) files It writes the contents of the first line of the file to the file TISTool WLJ which is read by TISTool to determine what material files are available Every TIS file that is found is output to the screen as shown in Figure 12 It is hoped that the simplicity of this system allows more users to easily use the basic heat transfer routines for their specific purpose

```
      The TIStool writes to an output file that is located in the same location
      as this executable in addtion to the screen.
      The output file can be named by the user.
      The TIStool will inform you of any errors you make during the input and
      allow you to correct them.

 press Enter to continue

 If you would like to update your insulation file, please enter a 1
 Otherwise, enter 0
1
        1 file(s) copied.
file: 10102.TIS
file: 10103.TIS
file: 10104.TIS
file: 10105.TIS
file: 10106.TIS
file: 10107.TIS
file: 10108.TIS
file: 10109.TIS
file: 10110.TIS
file: 10111.TIS
file: 10112.TIS
file: 10113.TIS
file: 10114.TIS
file: 10116.TIS
file: 10117.TIS
file: 10118.TIS
file: 10125.TIS
file: 11100.TIS
file: 11500.TIS
file: 11501.TIS
file: 11502.TIS
file: 11507.TIS
file: 11508.TIS
file: 11509.TIS
file: 11510.TIS
file: 11511.TIS
file: 11512.TIS
file: 11513.TIS
file: 11514.TIS
```

Figure 12 Updating the Master Insulation File

5 3 Multilayer Insulation Systems

Multilayer insulations are treated a little bit differently than standard materials In the early 1970's and mid-1990's there were several investigations into the roles of various combinations of radiation, solid conduction, and gas conduction/convection for different multilayer insulation systems (2) (3) (4) These investigations yielded several basic equations to determine the performance of multilayer insulation systems Meanwhile, Barron used these basic equations to develop a modified way to handle MLI systems layer by layer (5) Barron's equations are used in material 27000, 'MLI Dacron Spacer L-B-L (Barron)' From the original Lockheed flat plate

calorimeter, material 27004, 'Lockheed (CR-12025) - Unperforated DAM/Unconditioned Silk Net', was developed The main “Lockheed Report” (NASA-CR-13477) contained the equations for the following systems
(27003) 'Lockheed (CR-13477) - Unperforated DAM/Tissuepaper'
(27005) 'Lockheed (CR-13477) - Unperforated DAM/Conditioned Silk Net'
(27008) 'Lockheed (CR-13477) - Pattern S602 DAM/Silk Net'
(27009) 'Lockheed (CR-13477) - Pattern S603 DAM/Silk Net'
(27010) 'Lockheed (CR-13477) - Pattern S604 DAM/Silk Net'
(27011) 'Lockheed (CR-13477) - Pattern 937 DAM/Silk Net'
(27012) 'Lockheed (CR-13477) - Pattern 937S DAM/Silk Net'

Based on NASA TM-2004-213175, a “Modified Lockheed Equation” was developed for variable density MLI using perforated (0 5” holes with 2” spacing) double aluminized mylar with with Dacron netting The material numbers are
(27001) 'Modified Lockheed (MHTB) - Constant Density'
(27002) 'Modified Lockheed (MHTB) - Variable Density'

Special instructions for using these materials are that for the divisions, you must specify the number of layers (reflector and spacer) as the number of divisions The TISTool automatically sets the number of layers equal to the number of divisions specified and the layer density is the number of divisions divided by the material thickness specified The TISTool does a layer by layer analysis using these equations

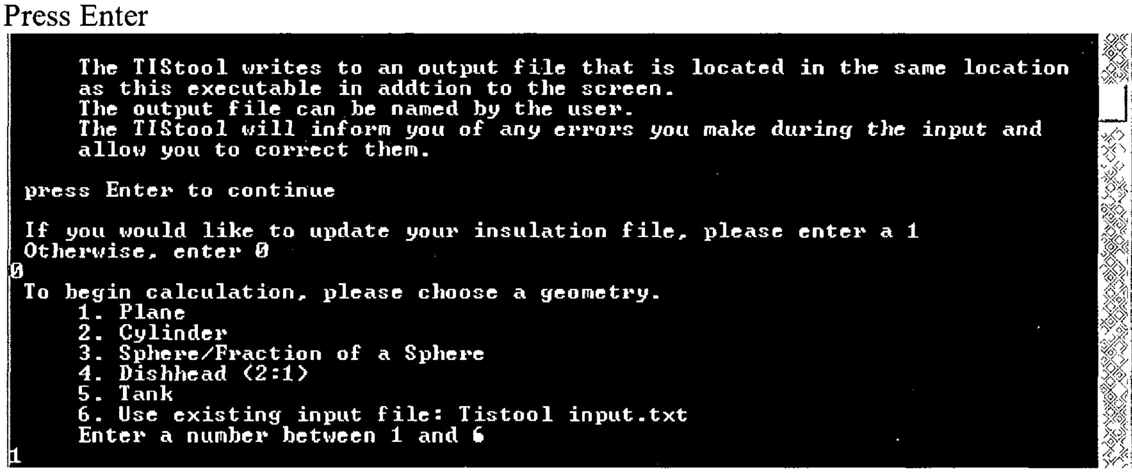
By including these equations, the authors by no means endorse the validity of the resulting data, often these equations are found to be a factor of 2 or more off of the actual heat transfer data More information on these materials can be found in section 8 0

6.0 Tutorials

The following tutorials show the usage of all TISTool options and geometries (but not all materials)
Note the actual characters to be typed are in quotation marks

6.1 Plane/Flat Plate

Select the plane or flat plate geometry by typing “1” in the TISTool command window
Press Enter



Enter a surface area of “2 0” m^2
Press Enter

```
If you would like to update your insulation file, please enter a 1
Otherwise, enter 0
0
To begin calculation, please choose a geometry.
    1. Plane
    2. Cylinder
    3. Sphere/Fraction of a Sphere
    4. Dishhead (2:1)
    5. Tank
    6. Use existing input file: Tistool input.txt
    Enter a number between 1 and 6
1
Please insert the planar area (m^2)
2.0
```

Type “90” for the cold boundary temperature in Kelvin
Press Enter
Type “n” for a fixed temperature boundary condition
Press Enter
Type “273” for the warm boundary temperature in Kelvin
Press Enter
Type “n” for a fixed temperature boundary condition
Press Enter

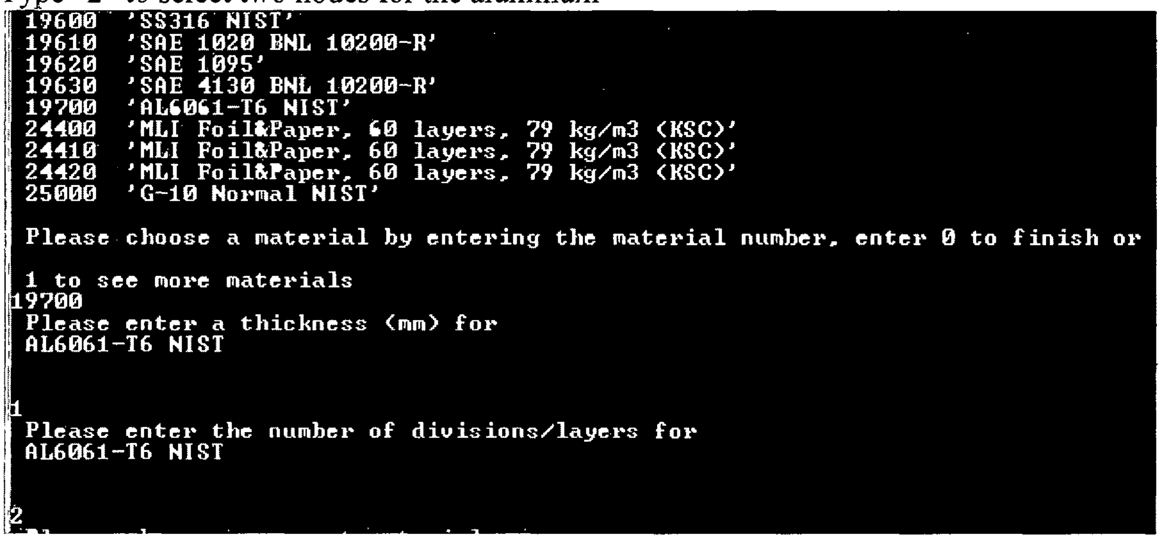
```
If you would like to update your insulation file, please enter a 1
Otherwise, enter 0
0
To begin calculation, please choose a geometry.
    1. Plane
    2. Cylinder
    3. Sphere/Fraction of a Sphere
    4. Dishhead (2:1)
    5. Tank
    6. Use existing input file: Tistool input.txt
    Enter a number between 1 and 6
1
Please insert the planar area (m^2)
2.0
Please enter the cold boundary temperature in Kelvin
90
Is there convection on the cold boundary? (Y/N)
n
Please enter the warm boundary temperature in Kelvin
273
Is there convection on the warm boundary? (Y/N)
n
```

Type “n” to change the default tolerance
Press Enter
Type “0 0001” to change the tolerance to 1 0E-4 K
Press Enter
Type “n” to change the default number of iterations
Press Enter
Type “50” to set the system to do a maximum of 50 iterations
Press Enter

```
Is the default tolerance of 1.0*10^(-5) appropriate? (Y/N)
n
Please enter your desired temperature tolerance (K)
0.0001
Is the default maximum iterations of 1000 appropriate? (Y/N)
n
Please enter your desired maximum number of iterations
50
```

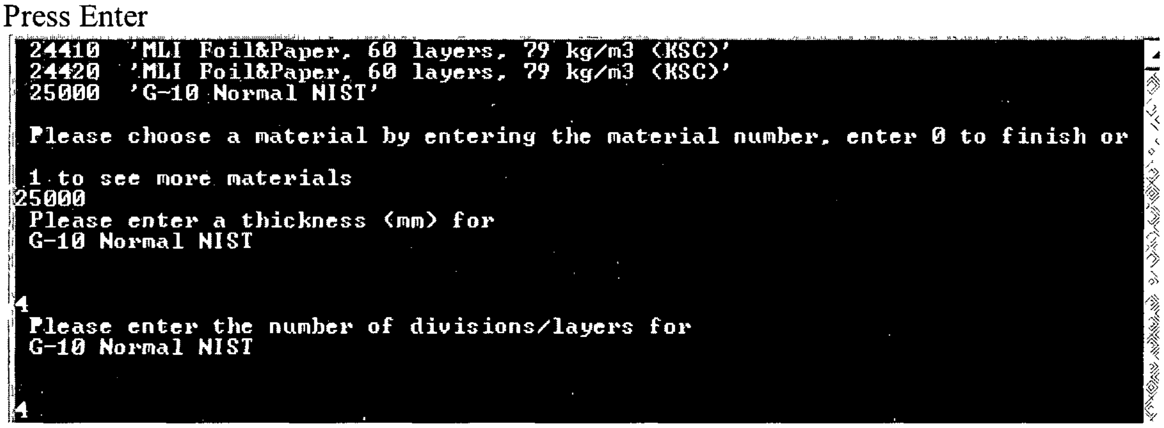
Type “1” to see more materials
Type “1” to see more materials
Type “1” to see more materials

Type “1” to see more materials
Type “1” to see more materials
Type “1” to see more materials
Type “19700” to choose 6061-T6 Aluminum as the cold mass material
Press Enter
Type “1” to set the aluminum thickness at 1.0 mm
Press Enter
Type “2” to select two nodes for the aluminum



```
 19600   'SS316 NIST'
 19610   'SAE 1020 BNL 10200-R'
 19620   'SAE 1095'
 19630   'SAE 4130 BNL 10200-R'
 19700   'AL6061-T6 NIST'
 24400   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 24410   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 24420   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 25000   'G-10 Normal NIST'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
19700
 Please enter a thickness (mm) for
 AL6061-T6 NIST


1
 Please enter the number of divisions/layers for
 AL6061-T6 NIST


2
```

Type “1” followed by enter several times until 25000 G-10 Normal NIST appears
Type “25000” to select G-10, Normal to warp fiber conductivity
Press Enter
Type “4” to set the thickness at 4 mm
Press Enter
Type “4” to choose 4 divisions within the G-10
Press Enter



```
 24410   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 24420   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 25000   'G-10 Normal NIST'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
25000
 Please enter a thickness (mm) for
 G-10 Normal NIST


4
 Please enter the number of divisions/layers for
 G-10 Normal NIST


4
```

Type “10104’ to select SOFI, BX-265, shaved as the next material in the insulation system
Press Enter
Type “15” to set the SOFI thickness to 15 mm
Press Enter
Type “5” to select 5 division within the SOFI
Press Enter
Type “1” to select a vacuum level of 1.0 millitorr (1.3*10^{-4} kPa)

Press Enter

```
Please choose a material by entering the material number, enter 0 to finish or

1 to see more materials
10104
Please enter a thickness (mm) for
SOFI, BX-265, shaved


15
Please enter the number of divisions/layers for
SOFI, BX-265, shaved


5
Please enter the vacuum level (millitorr) for
SOFI, BX-265, shaved


1
```

Type "0" to indicate that your insulation system design is complete
Press Enter

```
10110   'LCI#1, MLI + Aerogel Blankets'
10111   'Layered Pyrogel, Aspen'

Please choose a material by entering the material number, enter 0 to finish or

1 to see more materials
0
Name your output file, make sure to include the extension (.txt)
plate_tut.txt
```

This completes this tutorial, the output file named "plate_tut txt" should look something like the next figure

```
plate_tut - Notepad
File  Edit  Format  View  Help
This calculation used the basic geometry of a plane
   area       2 000 m^2
Boundary Conditions
   Inner Temperature        90 000 K
   Inner Convection          0 000 W/m^2-K
   Outer Temperature       273 000 K
   Outer Convection          0 000 W/m^2-K
   Tolerance               100E-03
   Maximum Iterations       50
Summary of Results
   Inner Surface Area        2 000 m^2
   Outer Surface Area        2 000 m^2
   Total Heat Load         190 251 W
   Inner Heat Flux          95 126 W/m^2
   Outer Heat Flux          95 438 W/m^2
   Thickness                20 000 mm
   koafi                    10 430 mW/m-K
```

Material	Matl #	thickness (m)	k-value (mW/m-K)	(r-Ri)/(Ro-Ri)	T(K)	Q(W)
AL6061-T6 NIST	19700	0 0000	92047 7978	0 0000	90 000	190 251
AL6061-T6 NIST	19700	0 0005	92047 7978	0 0250	90 001	188 385
AL6061 T6 NIST	19700	0 0010	92048 09,8	0 0500	90 001	190 885
G-10 Normal NIST	25000	0 0020	297 2101	0 1000	90 322	190 880
G-10 Normal NIST	25000	0 0030	297 6272	0 1500	90 643	190 874
G-10 Normal NIST	25000	0 0040	298 0438	0 2000	90 963	190 875
G-10 Normal NIST	25000	0 0050	298 4598	0 2500	91 283	190 876
SOFI BX-265 shaved	10104	0 0080	7 8780	0 4000	127 626	190 876
SOFI BX-265 shaved	10104	0 0110	7 8780	0 5500	163 970	190 876
SOFI BX-265 shaved	10104	0 0140	7 8780	0 7000	200 313	190 876
SOFI BX-265 shaved	10104	0 0170	7 8780	0 8500	236 657	190 876
SOFI BX-265 shaved	10104	0 0200	7 8780	1 0000	273 000	190 876

The total thickness was 20 mm, the heat loads were around 190 W, or 95 W/m2 Notice on the left hand side the various heat loads (not quite convergent) associated with changing the

tolerance of to 10^{-4} K Changing the number of iterations to where the system doesn't converge can show this effect further

6.2 Cylinder

Select the cylindrical geometry by typing "2" into the TISTool command window
Press Enter

```
     Currently, the TIStool is limited to 15 materials and 100 divisions for
     each insulation.

     The TIStool writes to an output file that is located in the same location
     as this executable in addtion to the screen.
     The output file can be named by the user.
     The TIStool will inform you of any errors you make during the input and
     allow you to correct them.

 press Enter to continue

 If you would like to update your insulation file, please enter a 1
 Otherwise, enter 0
0
 To begin calculation, please choose a geometry.
     1. Plane
     2. Cylinder
     3. Sphere/Fraction of a Sphere
     4. Dishhead (2:1)
     5. Tank
     6. Use existing input file: Tistool input.txt
     Enter a number between 1 and 6
2
```

Type in an inner radius of "0 0254" m (1 0 inch)
Press Enter
Type in a cylinder length of "1 0" m (39 4 inches)
Press Enter

```
     as this executable in addtion to the screen.
     The output file can be named by the user.
     The TIStool will inform you of any errors you make during the input and
     allow you to correct them.

 press Enter to continue

 If you would like to update your insulation file, please enter a 1
 Otherwise, enter 0
0
 To begin calculation, please choose a geometry.
     1. Plane
     2. Cylinder
     3. Sphere/Fraction of a Sphere
     4. Dishhead (2:1)
     5. Tank
     6. Use existing input file: Tistool input.txt
     Enter a number between 1 and 6
2
 Please insert the inner radius (m)
0.0254
 Please insert the cylinder length (m)
1.0
```

Next we define the boundary conditions
Type in a warm boundary of "77" K
Press Enter
Type "n" for no convection on the cold boundary
Press Enter
Type "300" for the warm boundary temperature (300 K)

Press Enter
Type “y” for convection on the warm boundary
Press Enter
Type “22 7” for the warm boundary convection coefficient h, (W/m^2-K)
Press Enter

```
To begin calculation, please choose a geometry.
     1. Plane
     2. Cylinder
     3. Sphere/Fraction of a Sphere
     4. Dishhead (2:1)
     5. Tank
     6. Use existing input file: Tistool input.txt
     Enter a number between 1 and 6
2
 Please insert the inner radius (m)
0.0254
 Please insert the cylinder length (m)
1.0
 Please enter the cold boundary temperature in Kelvin
77.0
 Is there convection on the cold boundary? (Y/N)
n
 Please enter the warm boundary temperature in Kelvin
300
 Is there convection on the warm boundary? (Y/N)
y
     Please input the convection coeficient, h (W/m2-K)
22.7
```

Type “y” to accept the default temperature tolerance
Press Enter
Type “y” to accept the default iteration tolerance
Press Enter

```
 Is there convection on the cold boundary? (Y/N)
n
 Please enter the warm boundary temperature in Kelvin
300
 Is there convection on the warm boundary? (Y/N)
y
     Please input the convection coeficient, h (W/m2-K)
22.7
 Is the default tolerance of 1.0*10^(-5) appropriate? (Y/N)
y
 Is the default maximum iterations of 1000 appropriate? (Y/N)
y
```

Next we get to choose the insulation system
Type “1” to see more materials
Type “1” to see more materials
Type “1” to see more materials
Type “1” to see more materials
Type “1” to see more materials
Type “19000” to choose SST 304/304L as the cold boundary material
Type “1 0” for a 1 mm thick tank
Type “1” for a single division of the tank (in the big picture the tank will not carry much thermal gradient, so not much insight is needed into the thermal gradients inside the tank wall)

```
 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
19000
 Please enter a thickness (mm) for
 SS304 NIST


1
 Please enter the number of divisions/layers for
 SS304 NIST


1
```

Type “1” to see more materials
Type “1” to see more materials
Type “11515” to choose Pyrogel Blanket, 2mm (KSC), NV
Type “8 0” for an 8 mm thick blanket of pyrogel (4 wraps of 2mm blanket)
Type “4” for a four divisions of the blanket, one for each wrap

```
 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
11515
 Please enter a thickness (mm) for
 Pyrogel Blanket, 2 mm (KSC)


8
 Please enter the number of divisions/layers for
 Pyrogel Blanket, 2 mm (KSC)


4
```

Type “1” to see more materials
Type “1” to see more materials
Type “11512” to choose Cryogel Blanket, 10mm (KSC), NV
Type “10 0” for an 10 mm thick blanket of cryogel (1 wraps of 10 mm blanket)
Type “5” for five divisions of the blanket, same spacing as the pyrogel blanket

```
 1 to see more materials
11512
 Please enter a thickness (mm) for
 Cryogel Blanket 10mm (KSC)


10
 Please enter the number of divisions/layers for
 Cryogel Blanket 10mm (KSC)


5
```

Type “0” to finish material entry
Press Enter
Type “cylinder_tut txt” to name the output file
Press Enter

```
[illegible]
 10106   'SOFI, NCFI 27-68, shaved'
 10107   'SOFI, NCFI 24-124, with rind'
 10108   'Nanogel Beads, Cabot, white'
 10109   'Composite Beads, black'
 10110   'LCI#1, MLI + Aerogel Blankets'
 10111   'Layered Pyrogel, Aspen'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials

0
 Name your output file, make sure to include the extension (.txt)
cylinder_tutorial.txt
[illegible]
```

TISTool now performs the calculation and exits

```
[illegible]
 10106   'SOFI, NCFI 27-68, shaved'
 10107   'SOFI, NCFI 24-124, with rind'
 10108   'Nanogel Beads, Cabot, white'
 10109   'Composite Beads, black'
 10110   'LCI#1, MLI + Aerogel Blankets'
 10111   'Layered Pyrogel, Aspen'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
0
 Name your output file, make sure to include the extension (.txt)
cylinder_tut.txt
 Thank you for using the
 Thermal Insulation Systems Analysis Tool
 Have a blessed day
Press any key to continue . . .
```

cylinder_tut txt can be found in the folder with the executable
Open cylinder_tut txt, is should look something like this

```
cylinder_tut - Notepad
File  Edit  Format  View  Help
This calculation used the basic geometry of a cylinder
   Inner Radius 0 025 m   Cylinder Length 1 000 m
Boundary Conditions
   Inner Temperature        77 000 K
   Inner Convection          0 000 W/m^2-K
   Outer Temperature       300 000 K
   Outer Convection         22 700 W/m^2-K
   Tolerance               100E-04
   Maximum Iterations      1000
Summary of Results
   Inner Surface Area         0 160 m^2
   Outer Surface Area         0 279 m^2
   Total Heat Load           34 831 W
   Inner Heat Flux          218 248 W/m^2
   Outer Heat Flux          124 839 W/m^2
   Thickness                 19 000 mm
   koafi                     14 234 mW/m-K
Material                          Matl #  thickness (m)  k-value (mW/m-K)  (r-Ri)/(Ro-Ri)   T(K)     Q(W)
SS304 NIST                        19000      0 0254        8120 7908           0 0000       77 000   34 831
SS304 NIST                        19000      0 0264        8120 7908           0 0526       77 026   34 831
Pyrogel Blanket  2 mm (KSC)       11515      0 0284          12 4004           0 1579      109 668   34 827
Pyrogel Blanket  2 mm (KSC)       11515      0 0304          13 0226           0 2632      138 633   34 827
Pyrogel Blanket  2 mm (KSC)       11515      0 0324          13 3909           0 3684      165 007   34 827
Pyrogel Blanket  2 mm (KSC)       11515      0 0344          13 5863           0 4737      189 444   34 827
Cryogel Blanket 10mm (KSC)        11512      0 0364          12 8414           0 5789      213 837   34 827
Cryogel Blanket 10mm (KSC)        11512      0 0384          13 3406           0 6842      236 060   34 827
Cryogel Blanket 10mm (KSC)        11512      0 0404          13 7700           0 7895      256 498   34 827
Cryogel Blanket 10mm (KSC)        11512      0 0424          13 7700           0 8947      275 947   34 827
Cryogel Blanket 10mm (KSC)        11512      0 0444          13 7700           1 0000      294 501   34 827
```

Thus the koafi was 14 234 mW/m-K, the heat flux on the inner vessel was 218 W/m^2 and the total heat transfer was 34 8 W Note that the insulation system is well defined in the outputs, showing the geometry, the thermal outputs and temperature distribution through the material

6 3 Sphere

Select the spherical geometry by typing "3" into the TISTool command window
Press Enter
Type "0 7674" to specify the inner radius of the sphere (this corresponds to roughly a 500 gallon sphere)
Press Enter
Type "1 0" to choose the whole sphere
Press Enter

```
To begin calculation, please choose a geometry.
     1. Plane
     2. Cylinder
     3. Sphere/Fraction of a Sphere
     4. Dishhead (2:1)
     5. Tank
     6. Use existing input file: Tistool input.txt
     Enter a number between 1 and 6
3
 Please insert the inner radius (m)
0.7674
 Please insert the sphere fraction (0<sf<1)
1.0
```

Type "20 4" for a cold temperature at the normal boiling point of liquid hydrogen
Press Enter

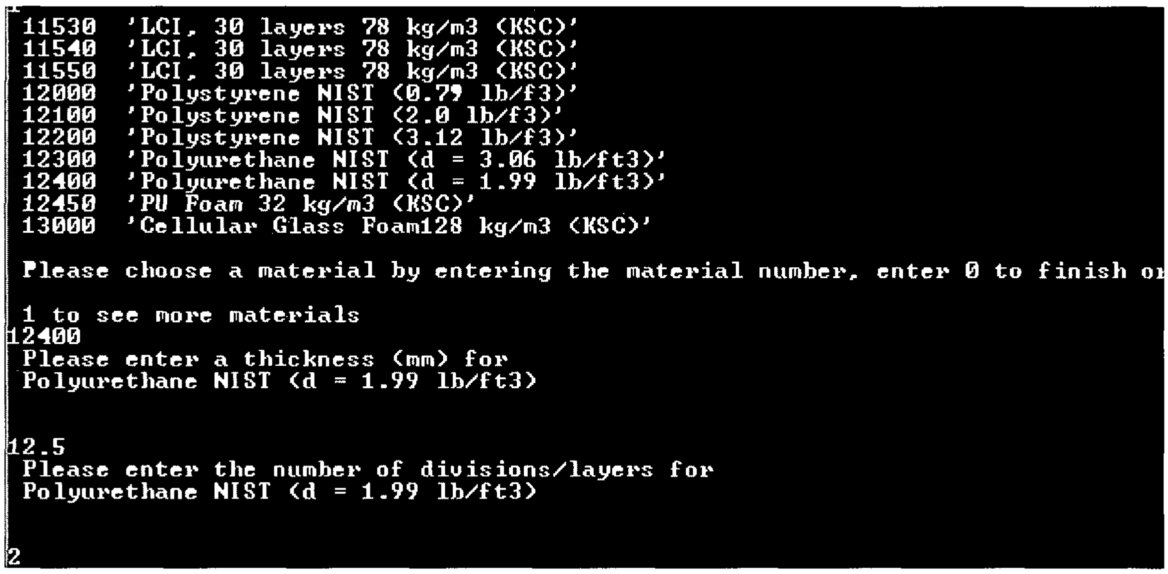
Type “y” to indicate convection on the cold surface
Press Enter
Type “15 0” to quantify the convection on the cold surface in W/m2/K
Press Enter
Type “250 0” to indicate the approximate temperature of a 200 km altitude parking orbit
Press Enter
Type “n” to indicate no convection on the warm boundary
Press Enter
Type “y” to accept the default tolerance
Press Enter
Type “y” to accept the default iteration scheme
Press Enter

```
 Please insert the inner radius (m)
0.7674
 Please insert the sphere fraction (0<sf<1)
1.0
 Please enter the cold boundary temperature in Kelvin
20.4
 Is there convection on the cold boundary? (Y/N)
y
     Please input the convection coeficient, h (W/m2-K)
15.0
 Please enter the warm boundary temperature in Kelvin
250.0
 Is there convection on the warm boundary? (Y/N)
n
 Is the default tolerance of 1.0*10^(-5) appropriate? (Y/N)
y
 Is the default maximum iterations of 1000 appropriate? (Y/N)
y
```

Type “1” five times (followed by enter) to get to the metals
Type “19700” to choose aluminum 6061-T6 as the tank material
Press Enter
Type “0 5” to set the tank thickness at 0 5 mm
Press Enter
Type “1” to choose one division of tank material
Press Enter

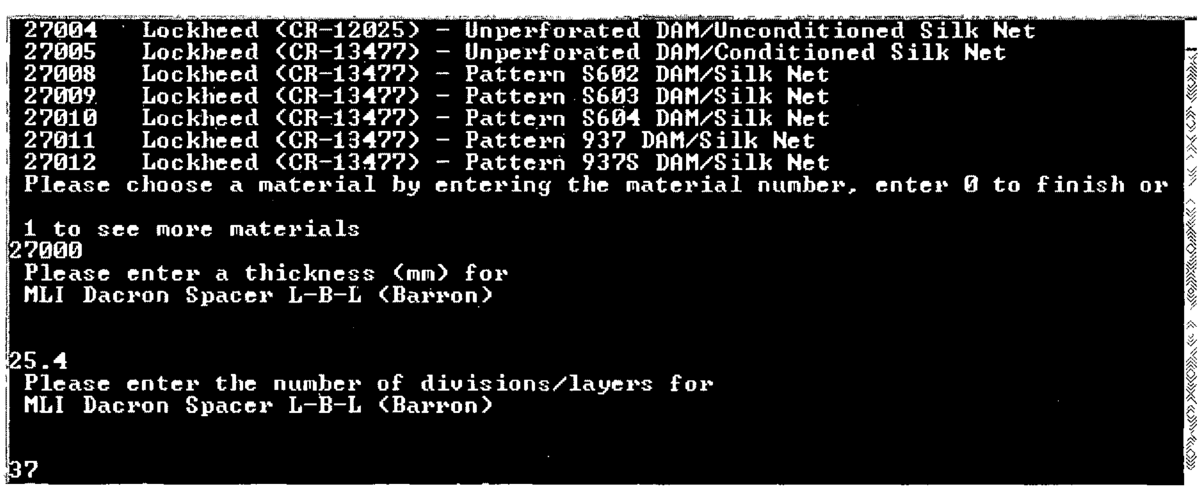
```
1
 19500  'Inconel-718 NIST'
 19600  'SS316 NIST'
 19610  'SAE 1020 BNL 10200-R'
 19620  'SAE 1095'
 19630  'SAE 4130 BNL 10200-R'
 19700  'AL6061-T6 NIST'
 24400  'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 24410  'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 24420  'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 25000  'G-10 Normal NIST'

 Please choose a material by entering the material number, enter 0 to finis

 1 to see more materials
19700
 Please enter a thickness (mm) for
 AL6061-T6 NIST


0.5
 Please enter the number of divisions/layers for
 AL6061-T6 NIST


1
```

Type “1” three times (followed by enter) to get to the foams
Type “12400” to select a substrate of 2 lb/ft^3 polyurethane foam
Press Enter
Type “12 5” to create a half of an inch of foam bonded to the tank wall
Press Enter
Type “2” to create 2 divisions of foam
Press Enter



```
 11530   'LCI, 30 layers 78 kg/m3 (KSC)'
 11540   'LCI, 30 layers 78 kg/m3 (KSC)'
 11550   'LCI, 30 layers 78 kg/m3 (KSC)'
 12000   'Polystyrene NIST (0.79 lb/f3)'
 12100   'Polystyrene NIST (2.0 lb/f3)'
 12200   'Polystyrene NIST (3.12 lb/f3)'
 12300   'Polyurethane NIST (d = 3.06 lb/ft3)'
 12400   'Polyurethane NIST (d = 1.99 lb/ft3)'
 12450   'PU Foam 32 kg/m3 (KSC)'
 13000   'Cellular Glass Foam128 kg/m3 (KSC)'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
12400
 Please enter a thickness (mm) for
 Polyurethane NIST (d = 1.99 lb/ft3)


12.5
 Please enter the number of divisions/layers for
 Polyurethane NIST (d = 1.99 lb/ft3)


2
```

Type “1” eight (8) times (followed by enter) to get to the intrinsic MLI list
Type “27000” to choose the Barron layer by layer MLI model (Dacron netting)
Press Enter
Type “25 4” to make the MLI 1 inch thick
Press Enter
Type “37” to create 37 layers of MLI (37 layer in 25 4 mm, gives 1 45 layer/mm layer density)
Press Enter



```
 27004    Lockheed (CR-12025) - Unperforated DAM/Unconditioned Silk Net
 27005    Lockheed (CR-13477) - Unperforated DAM/Conditioned Silk Net
 27008    Lockheed (CR-13477) - Pattern S602 DAM/Silk Net
 27009    Lockheed (CR-13477) - Pattern S603 DAM/Silk Net
 27010    Lockheed (CR-13477) - Pattern S604 DAM/Silk Net
 27011    Lockheed (CR-13477) - Pattern 937 DAM/Silk Net
 27012    Lockheed (CR-13477) - Pattern 937S DAM/Silk Net
 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
27000
 Please enter a thickness (mm) for
 MLI Dacron Spacer L-B-L (Barron)


25.4
 Please enter the number of divisions/layers for
 MLI Dacron Spacer L-B-L (Barron)


37
```

Type “0” to exit the materials selection list
Type “sphere_tut txt” to name the

```
10102  'Glass Bubbles, K1, 3M'
10103  'Perlite Powder, Ryolex'
10104  'SOFI, BX-265, shaved'
10105  'SOFI, NCFI 24-124, shaved'
10106  'SOFI, NCFI 27-68, shaved'
10107  'SOFI, NCFI 24-124, with rind'
10108  'Nanogel Beads, Cabot, white'
10109  'Composite Beads, black'
10110  'LCI#1, MLI + Aerogel Blankets'
10111  'Layered Pyrogel, Aspen'

Please choose a material by entering the material number, enter 0 to finish or

1 to see more materials
0
Name your output file, make sure to include the extension (.txt)
sphere_tut.txt
```

Now the program executes and is done within a few seconds

Looking in the same folder as the executable, sphere_tut txt should have been created Open the output file and it should look something like what is shown below All 37 layers of MLI are shown

```
sphere_tut - Notepad
File  Edit  Format  View  Help
Boundary Conditions
   Inner Temperature      20 400 K
   Inner Convection       15 000 W/m^2-K
   Outer Temperature     250 000 K
   Outer Convection        0 000 W/m^2-K
   Tolerance             100E 04
   Maximum Iterations    1000
Summary of Results
   Inner Surface Area          7 400 m^2
   Outer Surface Area          8 160 m^2
   Total Heat Load             2 698 W
   Inner Heat Flux             0 365 W/m^2
   Outer Heat Flux             0 327 W/m^2
   Thickness                  38 400 mm
   koafi                       0 058 mW/m K
Material                                           Matl #  thickness (m)  k-value (mW/m-K)  (r-Ri)/(Ro-Ri)    T(K)      Q(W)
AL6061-T6 NIST                                      19700      0 7674       29006 9478         0 0000        20 424  0 270E+01
AL6061 T6 NIST                                      19700      0 7679       29006 9478         0 0130        20 424  0 270E+01
Polyurethane NIST (d = 1 99 lb/ft3)                 12400      0 7742           9 8000         0 1758        20 652  0 267E+01
Polyurethane NIST (d = 1 99 lb/ft3)                 12400      0 7804           9 8000         0 3385        20 876  0 267E+01
MLI Dacron Spacer L B-L (Barron)                    27000      0 7811           0 0388         0 3564        27 042  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7818           0 0384         0 3743        33 264  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7825           0 0379         0 3922        39 551  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7831           0 0374         0 4101        45 907  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7838           0 0369         0 4279        52 338  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7845           0 0364         0 4458        58 844  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7852           0 0359         0 4637        65 426  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7859           0 0355         0 4816        72 083  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7866           0 0350         0 4994        78 811  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7873           0 0346         0 5173        85 607  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7880           0 0343         0 5352        92 463  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7886           0 0339         0 5531        99 370  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7893           0 0337         0 5709       106 319  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7900           0 0335         0 5888       113 296  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7907           0 0334         0 6067       120 287  0 267E+01
MLI Dacron Spacer L-B L (Barron)                    27000      0 7914           0 0333         0 6246       127 276  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7921           0 0333         0 6425       134 247  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7928           0 0335         0 6603       141 180  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7934           0 0337         0 6782       148 059  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7941           0 0340         0 6961       154 866  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7948           0 0344         0 7140       161 583  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7955           0 0349         0 7318       168 195  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7962           0 0354         0 7497       174 688  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7969           0 0361         0 7676       181 050  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7976           0 0368         0 7855       187 272  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7982           0 0377         0 8034       193 346  0 267E+01
MLI Dacron Spacer L-B-l (Barron)                    27000      0 7989           0 0386         0 8212       199 267  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 7996           0 0396         0 8391       205 031  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8003           0 0406         0 8570       210 637  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8010           0 0417         0 8749       216 084  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8017           0 0429         0 8927       221 375  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8024           0 0441         0 9106       226 510  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8031           0 0454         0 9285       231 494  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8037           0 0467         0 9464       236 331  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8044           0 0480         0 9642       241 024  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8051           0 0494         0 9821       245 579  0 267E+01
MLI Dacron Spacer L-B-L (Barron)                    27000      0 8058           0 0508         1 0000       250 000  0 267E+01
```

Several things are immediately apparent, the first is that the total heat load is just under 2 7 W, which gives a heat flux on the order of 0 35 W/m^2 (note to calculate the geometric mean heat flux, the square root of the product of the inner and outer heat flux is generally less that 5% off) This is a reasonable heat flux for this number of layers However, examining the temperature distribution, it is noted that the first layer supports a thermal gradient of approximately 7 K, this is low (generally one would expect a temperature difference of at least several 10's of K across the first shield), and thus the temperature distributions of this method is not entirely accurate (for MLI systems) due to the effects of radiation heat transfer Next, you may have noticed that your screen said that the solution did not converge, this is shown in the metallic tank, as it is shown to be transferring roughly 1% more heat than the other layers Examining the relative thermal conductivities shows that the aluminum has about four orders of magnitude greater thermal conductivity than foam which has a roughly three order magnitude greater thermal conductivity than the MLI, thus the seven order of magnitude difference means that there are almost not temperature gradients through the tank or foam

Other Exercises

Run this case on a flat plate and a cylinder to see the effects of shape on the calculation outputs

Run this case with various other intrinsic MLI functions to see the differential heating due to the various equations

6 4 Dishhead

Select the dishhead geometry by typing "4" into the TISTool command window
Press Enter
Type "0 7674" to set the inner radius of the dishhead
Press Enter
Type "1 0" to specify a complete dishhead

```
    conductivity or a specified input file (.TIS).

    For each material, a thickness, the number of divisions of that material
    desired, and a vacuum level or specified thermal conductivity is input.
    Currently, the TIStool is limited to 15 materials and 100 divisions for
    each insulation.

    The TIStool writes to an output file that is located in the same location
    as this executable in addtion to the screen.
    The output file can be named by the user.
    The TIStool will inform you of any errors you make during the input and
    allow you to correct them.

 press Enter to continue

 If you would like to update your insulation file, please enter a 1
 Otherwise, enter 0
0
 To begin calculation, please choose a geometry.
    1. Plane
    2. Cylinder
    3. Sphere/Fraction of a Sphere
    4. Dishhead (2:1)
    5. Tank
    6. Use existing input file: Tistool input.txt
    Enter a number between 1 and 6
4
 Please insert the inner radius (m)
0.7674
 Please insert the dishhead fraction (0<sf<1)
1.0
```

Type “38 0” to set the cold boundary to the normal boiling point of liquid fluorine
Press Enter
Type “n” to turn off cold boundary convection
Press Enter
Type “293 15” to set the warm boundary temperature to ambient room temperature
Press Enter
Type “n” to turn off warm boundary convection
Press Enter
Type “y” to accept the default tolerance
Press Enter
Type “y” to accept the default iteration scheme
Press Enter

```
4
 Please insert the inner radius (m)
0.7674
 Please insert the dishhead fraction (0<sf<1)
1.0
 Please enter the cold boundary temperature in Kelvin
38.0
 Is there convection on the cold boundary? (Y/N)
n
 Please enter the warm boundary temperature in Kelvin
293.15
 Is there convection on the warm boundary? (Y/N)
n
 Is the default tolerance of 1.0*10^(-5) appropriate? (Y/N)
y
 Is the default maximum iterations of 1000 appropriate? (Y/N)
y
```

Type “1” six times (followed by enter) to get to the list of metals
Type “19500” to select Inconel-718 as the tank material
Press Enter
Type “10 0” to set the tank wall thickness to 10 mm
Press Enter
Type “2” to select 2 divisions within the tank wall
Press Enter

```
 19700   'AL6061-T6 NIST'
 24400   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 24410   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 24420   'MLI Foil&Paper, 60 layers, 79 kg/m3 (KSC)'
 25000   'G-10 Normal NIST'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
19500
 Please enter a thickness (mm) for
 Inconel-718 NIST


10.0
 Please enter the number of divisions/layers for
 Inconel-718 NIST


2
```

Type “1” three times to get to fine perlite
Type “14420” to select Fine Perlite 128 kg/m3, NV

Press Enter
Type “30 0” to specify a 30 mm gap filled with perlite
Press Enter
Type “10” to set up 10 nodes within the perlite
Press Enter

```
 14420   'Fine Perlite 128 kg/m3 (KSC)'
 14500   'COARSE PERLITE (Barron)'
 14600   'PERLITE  (Barron) (50 kg/m3)'
 14700   'PERLITE (Barron) (210 kg/m3)'
 14800   'Santocel (Barron)'
 16000   'Polyethelyne-teraphthalate  NIST'
 16100   'Fine Perlite 128 kg/m3 (KSC)'
 16200   'Fine Perlite 128 kg/m3 (KSC)'

 Please choose a material by entering the material number, enter 0 to finish o

 1 to see more materials
14420
 Please enter a thickness (mm) for
 Fine Perlite 128 kg/m3 (KSC)


30.0
 Please enter the number of divisions/layers for
 Fine Perlite 128 kg/m3 (KSC)


10
```

Type “1” four times to get to the gases
Type “17001” to select gaseous nitrogen
Press enter
Type “30 0” to specify a 30 mm gap between the perlite and outer wall that is filled with GN2
Press enter
Type “5” to create 5 nodes within the GN2

```
 16300   'Fiberglass 16 kg/m3 (KSC)'
 17001   'Gaseous Nitrogen (NIST)'
 17002   'Gaseous Helium (NIST)'
 17003   'Gaseous Hydrogen (NIST)'
 17004   'Gasous Argon (NIST)'
 17005   'Gaseous Neon (NIST)'
 17006   'Gaseous Oxygen (NIST)'
 17007   'Gaseous Krypton (NIST)'
 17008   'Gaseous Xenon (NIST)'
 19000   'SS304 NIST'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
17001
 Please enter a thickness (mm) for
 Gaseous Nitrogen (NIST)


30.0
 Please enter the number of divisions/layers for
 Gaseous Nitrogen (NIST)


5
```

Type “1” six times (followed by enter) to get to the list of metals
Type “19610” to select SAE 1020 carbon steel as the outer vessel
Press Enter

Type "20 0" to set the wall thickness to 20 mm
Press Enter
Type "4" to set up 4 nodes within the carbon steel

```
 1 to see more materials
19610
 Please enter a thickness (mm) for
 SAE 1020 BNL 10200-R


20.0
 Please enter the number of divisions/layers for
 SAE 1020 BNL 10200-R


4
```

Type "0" to exit the materials selection process
Press Enter
Type "dish_tut txt" to name the output file

```
 10108  'Nanogel Beads, Cabot, white'
 10109  'Composite Beads, black'
 10110  'LCI#1, MLI + Aerogel Blankets'
 10111  'Layered Pyrogel, Aspen'

 Please choose a material by entering the material number, enter 0 to finish or

 1 to see more materials
0
 Name your output file, make sure to include the extension (.txt)
dish_tut.txt
```

Now the heat transfer analysis takes place and the program writes the output file to the same folder in which the executable is located Find this folder and open the output file, it should look something very similar to below A few things catch the eye in this output file Once again, there is very little temperature drop across either of the metallic sections Also, checking the outer temperature of the nitrogen gas, it is above the normal boiling point of nitrogen, this will drastically cut down on the liquefaction as the perlite will prevent large scale convection of the gas to the cold surface, however a pressure drop will probably occur This would make this an impractical insulation system to actually implement The radius of the dishhead is listed as twice the value that was inputted, thus the inputted value was assumed to be the height of the dishhead, keep this in mind for future calculations

dish_tut - Notepad

File Edit Format View Help

```
This calculation used the basic geometry of a dishhead
   Inner Radius 1 535 m   Fraction of Dish 0 067
Boundary Conditions
   Inner Temperature       38 000 K
   Inner Convection         0 000 W/m^2-K
   Outer Temperature      293 150 K
   Outer Convection         0 000 W/m^2-K
   Tolerance              100E-04
   Maximum Iterations     1000
Summary of Results
   Inner Surface Area          1 983 m^2
   Outer Surface Area          2 222 m^2
   Total Heat Load           217 286 W
   Inner Heat Flux           109 579 W/m^2
   Outer Heat Flux            97 965 W/m^2
   Thickness                  90 000 mm
   koafi                      36 511 mW/m-K
```

Material	Matl #	thickness (m)	k-value (mw/m-K)	(r-Ri)/(Ro-Ri)	T(K)	Q(W)
Inconel-718 NIST	19500	1 5348	4596 3961	0 0000	38 000	0 217E+03
Inconel-718 NIST	19500	1 5398	4596 3961	0 0556	38 119	0 217E+03
Inconel-718 NIST	19500	1 5448	4605 1516	0 1111	38 237	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5478	32 0000	0 1444	48 358	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5508	32 0000	0 1778	58 439	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5538	32 0000	0 2111	68 482	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5568	32 0000	0 2444	78 486	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5598	32 0000	0 2778	88 452	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5628	32 0000	0 3111	98 379	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5658	32 0000	0 3444	108 269	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5688	32 0000	0 3778	118 120	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5718	32 0000	0 4111	127 934	0 217E+03
Fine Perlite 128 kg/m3 (KSC)	14420	1 5748	32 0000	0 4444	137 711	0 217E+03
Gaseous Nitrogen (NIST)	17001	1 5808	15 2469	0 5111	178 515	0 217E+03
Gaseous Nitrogen (NIST)	17001	1 5868	18 2975	0 5778	212 260	0 217E+03
Gaseous Nitrogen (NIST)	17001	1 5928	20 7212	0 6444	241 832	0 217E+03
Gaseous Nitrogen (NIST)	17001	1 5988	22 7702	0 7111	268 542	0 217E+03
Gaseous Nitrogen (NIST)	17001	1 6048	24 5608	0 7778	293 119	0 217E+03
SAE 1020 BNL 10200-R	19610	1 6098	63959 5468	0 8333	293 127	0 217E+03
SAE 1020 BNL 10200-R	19610	1 6148	63959 5925	0 8889	293 135	0 217E+03
SAE 1020 BNL 10200-P	19610	1 6198	63959 6380	0 9444	293 142	0 217E+03
SAE 1020 BNL 10200-R	19610	1 6248	63959 6833	1 0000	293 150	0 218E+03

Other Excercises

Run same analysis, but with helium as the interstitial gas

Try all of the other gasses in TISTool to get a feel for their properties

6.5 Tank

Select the tank geometry by typing "5" into the TISTool command window
Press Enter
Type "2 0" to set the inner radius of the cylinder to 2 m
Press Enter
Type "1 0" to set the length of the cylinder to 1 m
Press Enter
Type "1" to set the dishhead fraction to 1
Press Enter

```
To begin calculation, please choose a geometry.
      1. Plane
      2. Cylinder
      3. Sphere/Fraction of a Sphere
      4. Dishhead (2:1)
      5. Tank
      6. Use existing input file: Tistool input.txt
      Enter a number between 1 and 6
5
 Please insert the inner radius (m)
2.0
 Please insert the cylinder length (m)
1.0
 Please insert the dishhead fraction (0<sf<1)
1
```

Type "77 4" to set the cold boundary temperature to 77 4 K, the normal boiling point of liquid nitrogen

Press Enter
Type “n” to turn off the cold boundary convection
Press Enter
Type “305” to set the warm boundary temperature to 305 K
Press Enter
Type “n” to turn off the warm boundary convection
Press Enter
Type “y” to accept the default conversion tolerance
Press Enter
Type “y” to accept the maximum iterations for convergence
Press Enter

```
 Please insert the inner radius (m)
2.0
 Please insert the cylinder length (m)
1.0
 Please insert the dishhead fraction (0<sf<1)
1
 Please enter the cold boundary temperature in Kelvin
77.4
 Is there convection on the cold boundary? (Y/N)
n
 Please enter the warm boundary temperature in Kelvin
305
 Is there convection on the warm boundary? (Y/N)
n
 Is the default tolerance of 1.0*10^(-5) appropriate? (Y/N)
y
 Is the default maximum iterations of 1000 appropriate? (Y/N)
y
```

Type “10107” to choose SOFI, NCFI 24-124 with rind as the insulation material
note is has been previously shown that the metallic inner walls have little if any effect on the total system heat transfer
Press Enter
Type “25 4” to set the total thickness of the foam to 1 inch
Press Enter
Type “15” to create 15 nodes within the foam
Press Enter
Type “760000” to set the vacuum level to 760,000 millitorr (760 torr = 14 7 psia)
Press Enter
Type “0” to exit the material selection look
Press Enter
Type “tank_tut txt” to name the output file
Press Enter
Now the TISTool does the heat transfer analysis on the cylindrical portion and the dishhead portion separately Since two different geometries are analyzed, the process will take approximately twice as long Both geometries are output to the file Opening the file shows that indeed the two geometries are both output with the temperature distributions for each The total heat load assumes two domes and one cylinder The dish fraction is calculated by TISTool as before

```
To exit the materials loop, select the material "0"
99999   User Defined Insulation

10102  'Glass Bubbles, K1, 3M'
10103  'Perlite Powder, Ryolex'
10104  'SOFI, BX-265, shaved'
10105  'SOFI, NCFI 24-124, shaved'
10106  'SOFI, NCFI 27-68, shaved'
10107  'SOFI, NCFI 24-124, with rind'
10108  'Nanogel Beads, Cabot, white'
10109  'Composite Beads, black'
10110  'LCI#1, MLI + Aerogel Blankets'
10111  'Layered Pyrogel, Aspen'

Please choose a material by entering the material number, enter 0 to finish or

1 to see more materials
10107
Please enter a thickness (mm) for
SOFI, NCFI 24-124, with rind


25.4
Please enter the number of divisions/layers for
SOFI, NCFI 24-124, with rind


15
Please enter the vacuum level (millitorr) for
SOFI, NCFI 24-124, with rind


760000
```

tank_tut - Notepad

File Edit Format View Help

```
This calculation used the basic geometry of a tank
Cylinder Inner Radius 2 000 m   Cylinder Length 1 000 m
Head Inner Radius 2 000 m   Fraction of Dish 067
Boundary Conditions
   Inner Temperature       77 400 K
   Inner Convection         0 000 W/m^2-K
   Outer Temperature      305 000 K
   Outer Convection         0 000 W/m^2-K
   Tolerance              000E+00
   Maximum Iterations     1000
Summary of Results
   Inner Surface Area          39 437 m^2
   Outer Surface Area          39 980 m^2
   Total Heat Load           8322 452 W
   Inner Heat Flux            210 653 W/m^2
   Outer Heat Flux            208 017 W/m^2
   Thickness                   25 400 mm
   koafi                       23 390 mW/m K
 Domed section
Material                                  Matl #  thickness (m)  k-value (mw/m-K)  (r-Ri)/(Ro-Ri)   T(K)      Q(W)
SOFI  NCFI 24-124  with rind               10107     4 0000         23 3630           0 0000       77 400  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0017         23 3630           0 0667       92 663  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0034         23 3630           0 1333      107 914  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0051         23 3630           0 2000      123 151  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0068         23 3630           0 2667      138 376  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0085         23 3630           0 3333      153 587  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0102         23 3630           0 4000      168 786  0 284E+04
SOFI  NCFI 24 124  with rind               10107     4 0119         23 3630           0 4667      183 972  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0135         23 3630           0 5333      199 145  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0152         23 3630           0 6000      214 306  0 284E+04
SOFI  NCFI 24 124  with rind               10107     4 0169         23 3630           0 6667      229 453  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0186         23 3630           0 7333      244 588  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0203         23 3630           0 8000      259 710  0 284E+04
SOFI  NCFI 24 124  with rind               10107     4 0220         23 3630           0 8667      274 820  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0237         23 3630           0 9333      289 916  0 284E+04
SOFI  NCFI 24-124  with rind               10107     4 0254         23 3630           1 0000      305 000  0 284E+04


 Cylinder section
Material                                  Matl #  thickness (m)  k-value (mw/m-K)  (r-Ri)/(Ro-Ri)   T(K)      Q(W)
SOFI  NCFI 24-124  with rind               10107     2 0000         23 3630           0 0000       77 400  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0017         23 3630           0 0667       92 663  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0034         23 3630           0 1333      107 913  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0051         23 3630           0 2000      123 150  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0068         23 3630           0 2667      138 375  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0085         23 3630           0 3333      153 586  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0102         23 3630           0 4000      168 785  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0119         23 3630           0 4667      183 971  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0135         23 3630           0 5333      199 144  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0152         23 3630           0 6000      214 304  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0169         23 3630           0 6667      229 452  0 265E+04
SOFI  NCFI 24 124  with rind               10107     2 0186         23 3630           0 7333      244 587  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0203         23 3630           0 8000      259 709  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0220         23 3630           0 8667      274 819  0 265E+04
SOFI  NCFI 24 124  with rind               10107     2 0237         23 3630           0 9333      289 916  0 265E+04
SOFI  NCFI 24-124  with rind               10107     2 0254         23 3630           1 0000      305 000  0 265E+04
```

7.0Appendix A: Cryostat-100 Test Apparatus

8.0 Appendix B: Insulation Systems Test Data

9.0 Appendix C: References

1 **Demko, J. A , Fesmire, J E. and Augustynowicz, S D** Design Tool for Cryogenic Thermal Insulation Systems *Advances in Cryogenic Engineering Transactions of the Cryogenic Engineering Conference - CEC* 2008, Vol 53A, pg 145-151

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3 **Keller, C W , Cunnington, G R. and Glassford, A. P.** *Thermal Performance of Multi-layer Insulations, Final Report* Sunnyvale, CA Lockheed Missile and Space Company, 1974 Contract NAS3-14377

4 **Hastings, L , Hedayat, A and Brown, T M** *Analytical Modeling and Test Correlation of Variable Density Multilayer Insulation for Cryogenic Storage* 2004 NASA-TM-2004-213175

5 **Barron, Randall F.** *Cryogenic Heat Transfer* Ann Arbor, MI Edwards Brothers, 1999